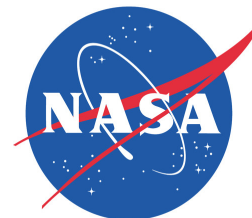


Evaluation of CERES-MODIS Ed4 cloud temperatures and heights using ARM ground-based observations over the Arctic.

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Baike Xi and Xiquan Dong, University of Arizona

Patrick Minnis and William Smith Jr., NASA/Langley Research Center



Data and Methodology

CERES-MODIS Ed4 data:

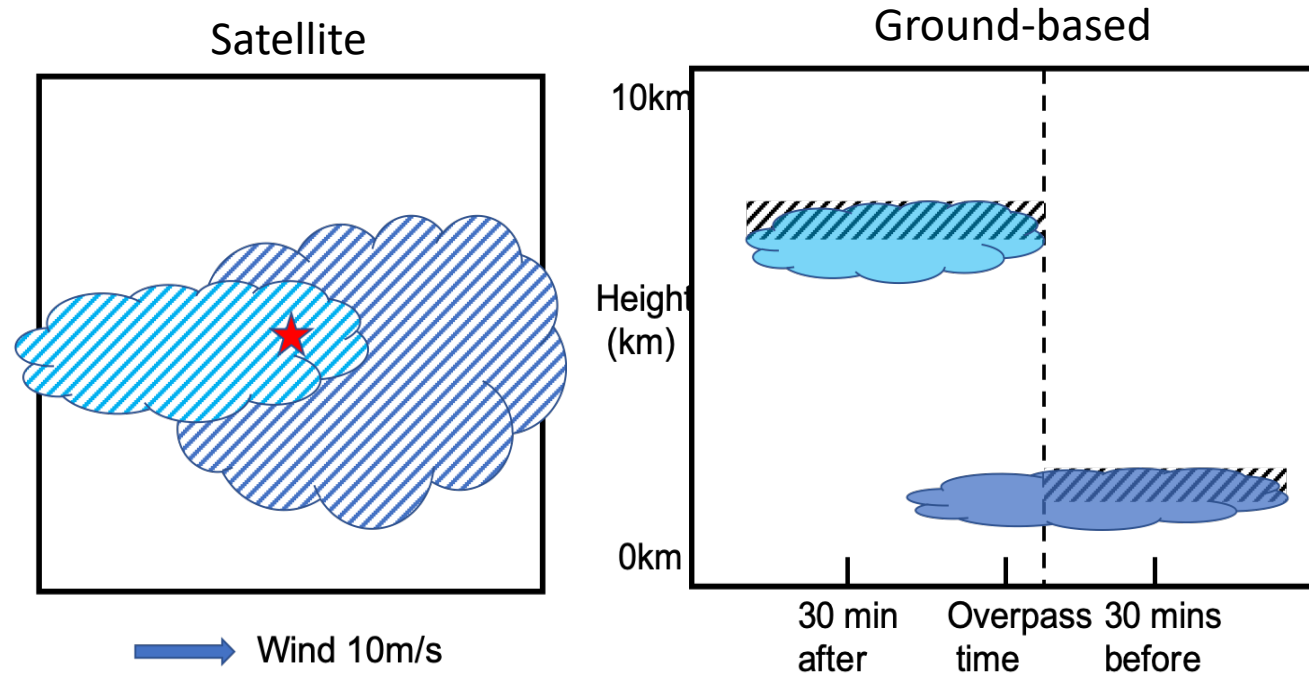
- Use the CM Single Scanner Footprint (SSF) product
- Select Terra and Aqua overpasses within the 30 km × 30 km box centered at ARM site

Ground-base observations at ARM NSA site:

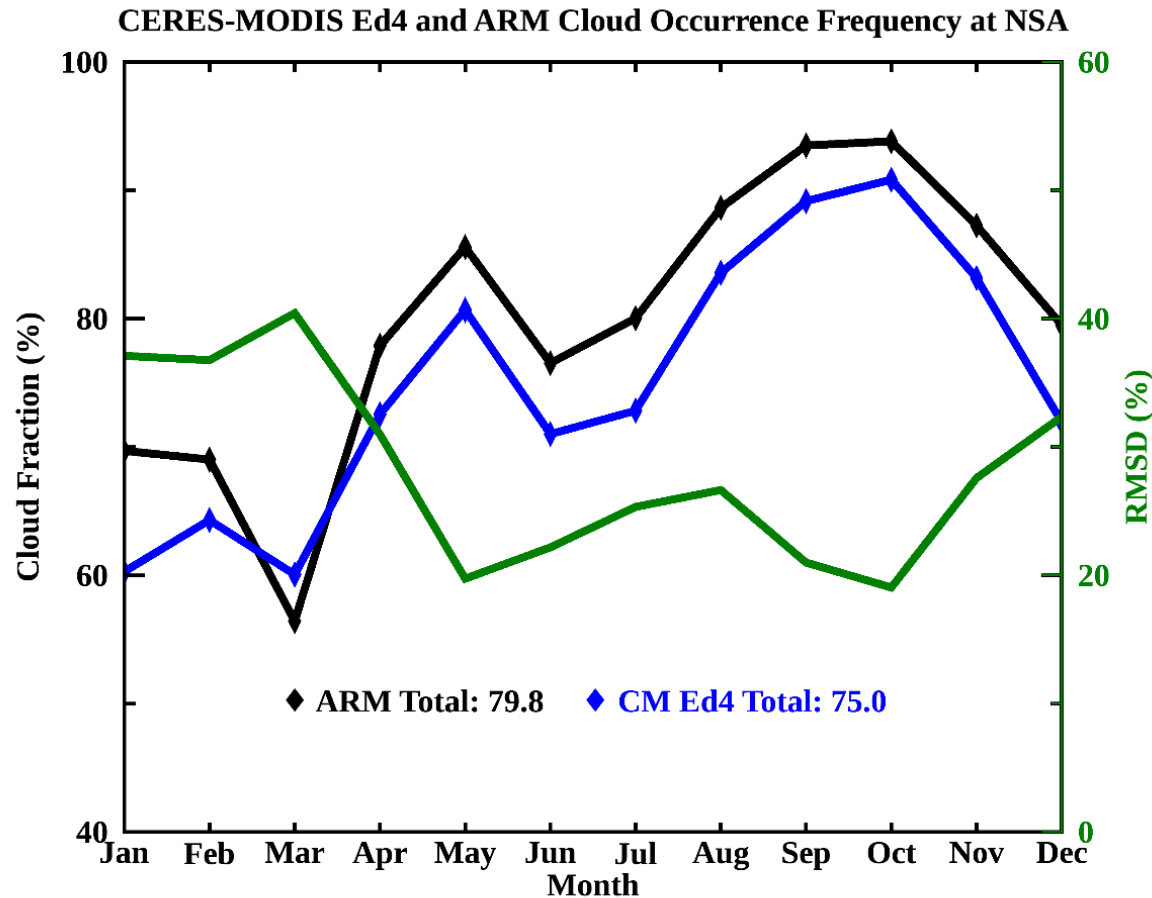
- 1-h average ground-based observations centered at the time of each satellite overpass

Multi-layer conditions:

- When two distinct layers are detected by CERES-MODIS, the cloud top height and temperature for each footprint are weighted by the cloud fraction of each layer.
- Similarly, when multi-layer clouds are detected by ground-based observations, the upper-most cloud height and temperature are used to calculate the hourly mean



Cloud mask

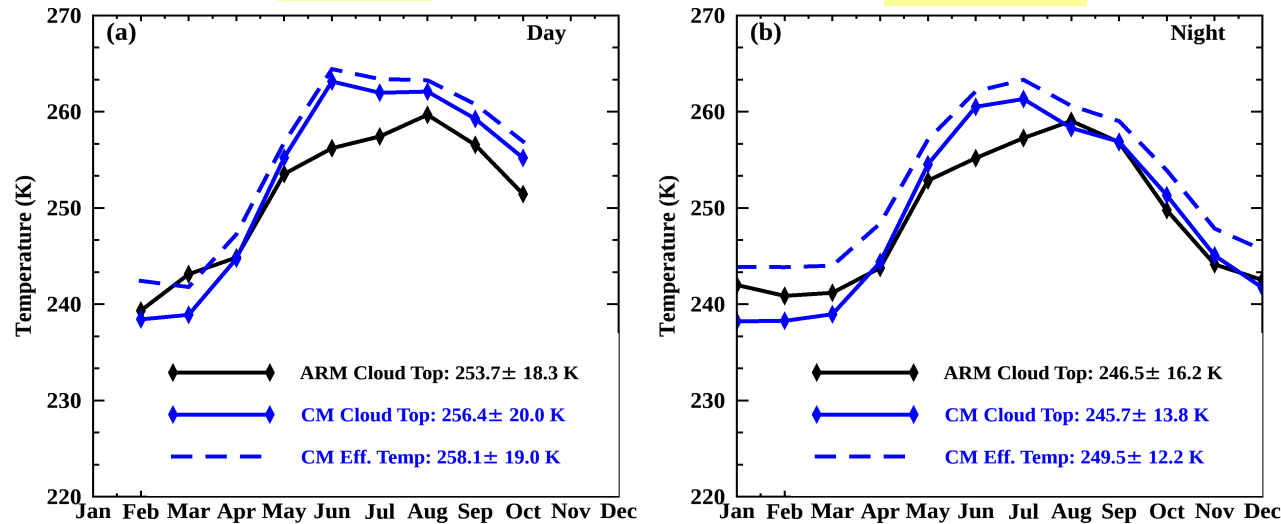


- January 2001 – December 2010 (July 2002 to December 2010 for Aqua satellite)
- Total of 46,486 Terra and Aqua overpasses
- CERES-MODIS (CM) Ed4 cloud mask data is able to represent the monthly mean cloud occurrence frequency over the Arctic
- Root mean square differences (RMSD) vary from ~20% in summer to ~40% in winter

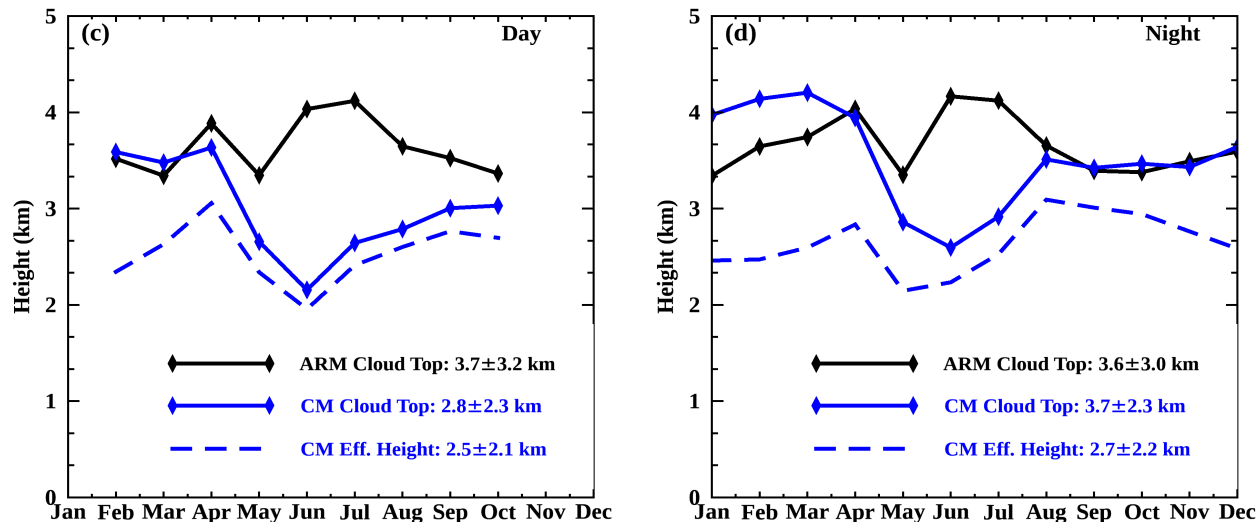
Cloud Temperature and Height

Day

Night



CERES-MODIS Ed4 and ARM Cloud Height at ARM NSA

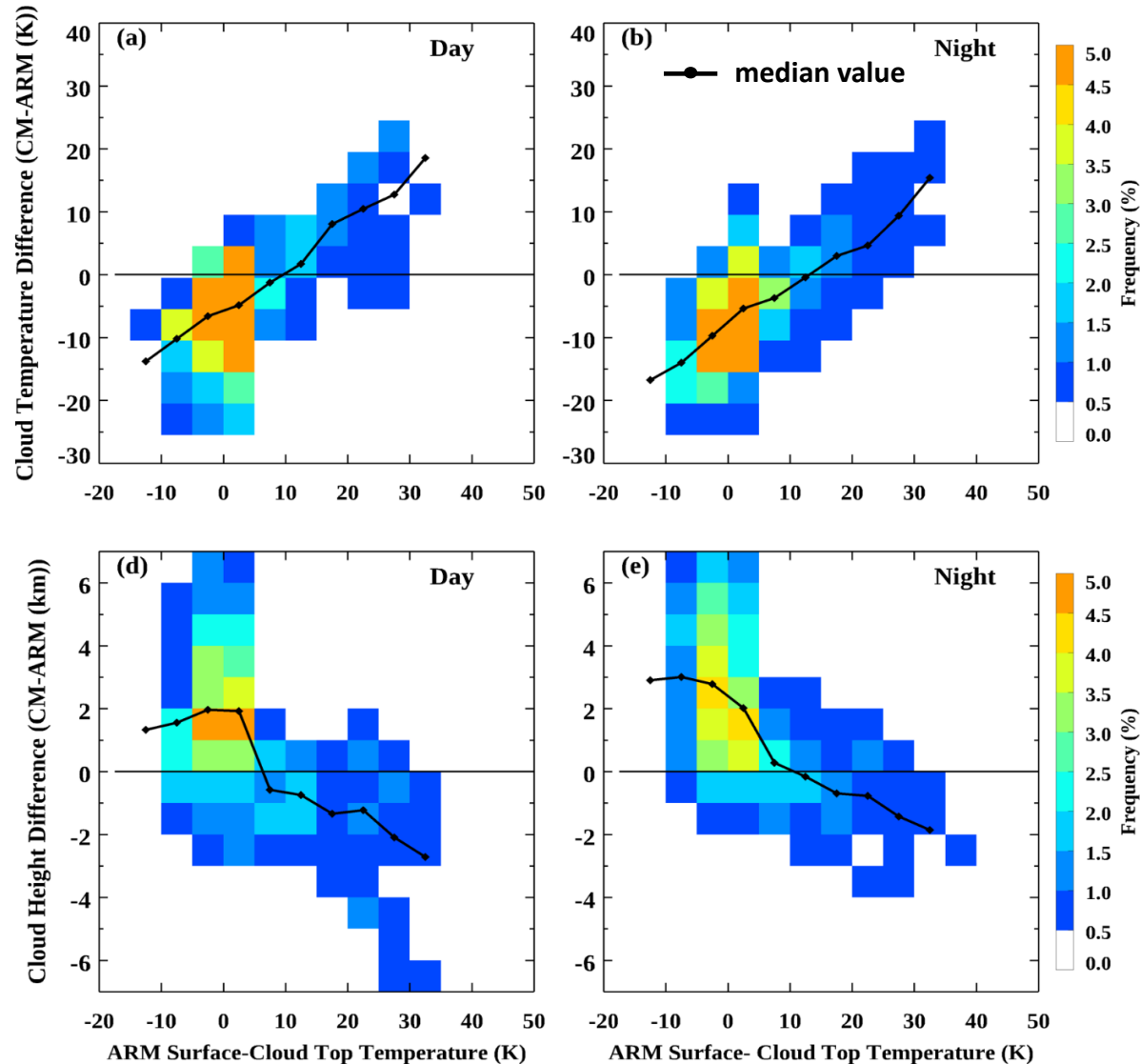


- CM retrieved cloud top temperatures (T_{top}) are 2-5 K warmer than ARM T_{top} in summer
- CM retrieved cloud top heights (Z_{top}), which is based on T_{top} retrieval, are 0.2-1.5 km lower than ARM Z_{top} in summer
- CM nighttime retrievals agree slightly better with ARM observations than daytime

Why do CM retrievals have larger difference with ARM in summer?

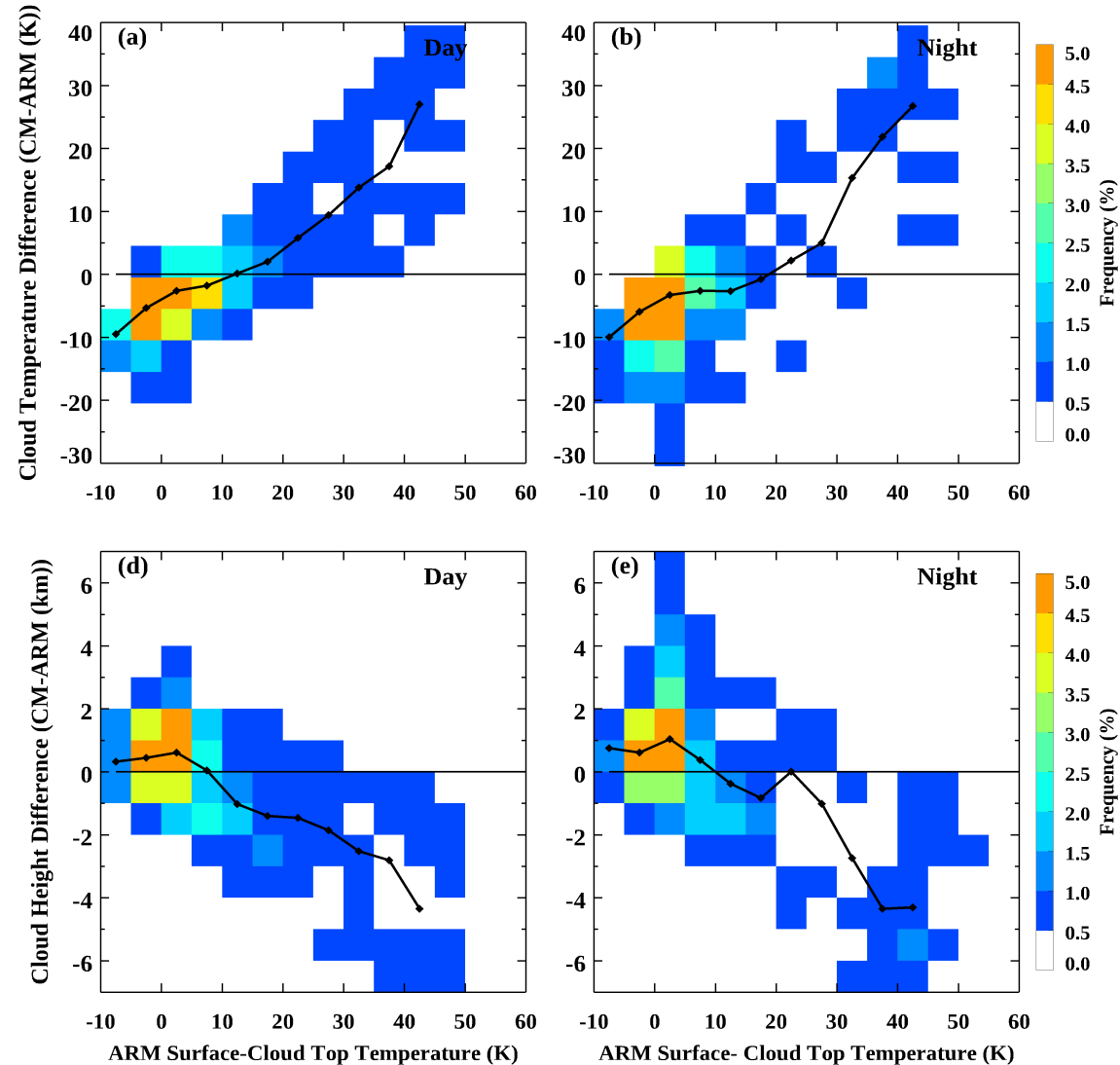
Sensitivity of CM retrievals to cloud top and surface temperature difference

January – March



- With temperature inversions (T_{top} warmer than surface), CM retrieved T_{top} are colder than ARM measurements,
- The median T_{top} differences are -6 to -17 K
- CM retrieved Z_{top} are higher than ARM, the median differences are 1 to 2 km
- Difference are larger for night time

May—July

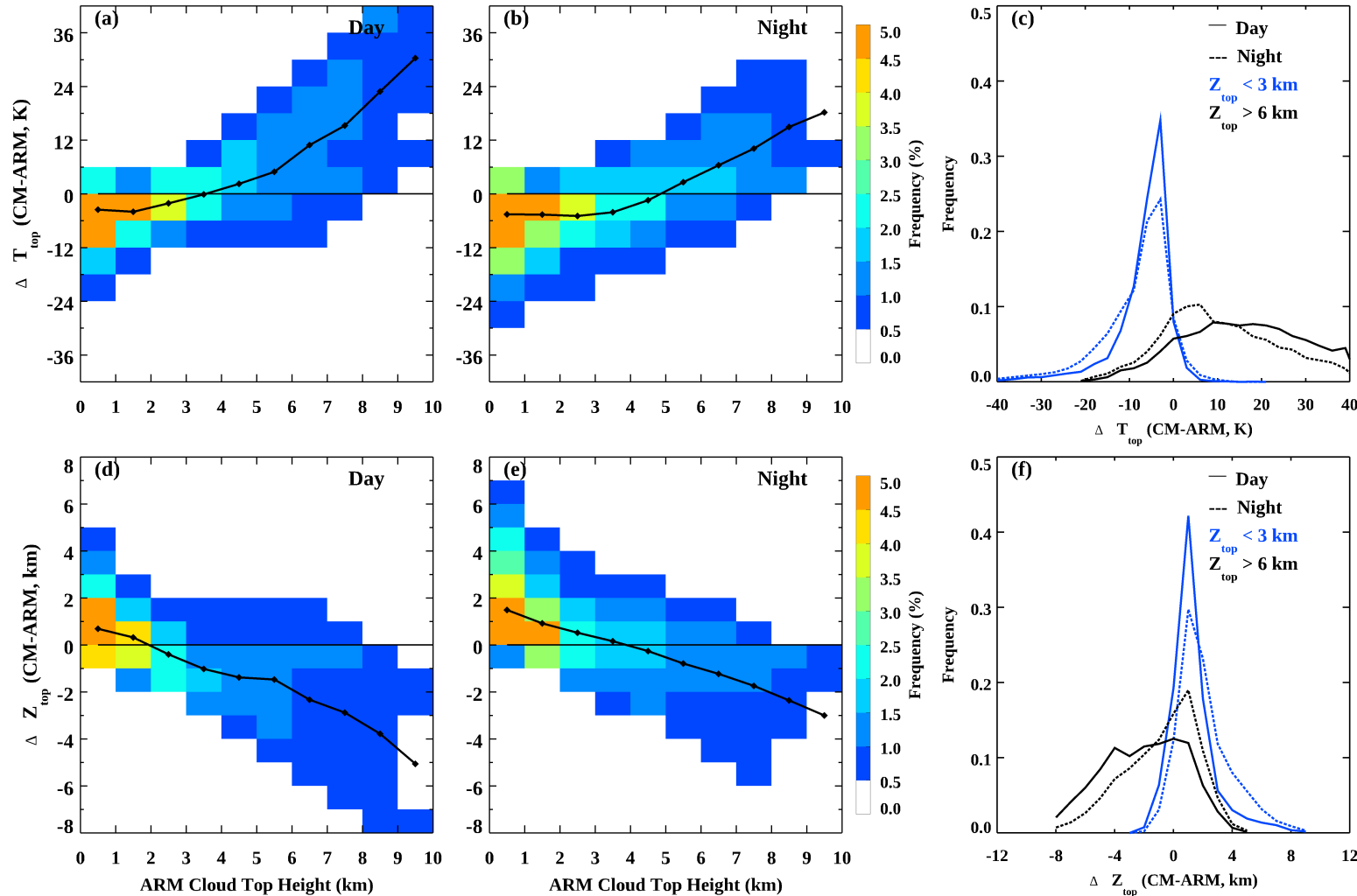


Compared to winter months:

- In summer, less samples have T_{top} warmer than surface
- Difference between CM retrievals and ARM measurements are smaller in summer than in winter under T inversions
- More high clouds in summer than in winter
- For high clouds, CM retrieved T_{top} are warmer than ARM T_{top} and CM Z_{top} are lower than ARM
- Due to difference for high clouds, monthly mean CM T_{top} (Z_{top}) are warmer (lower) than ARM

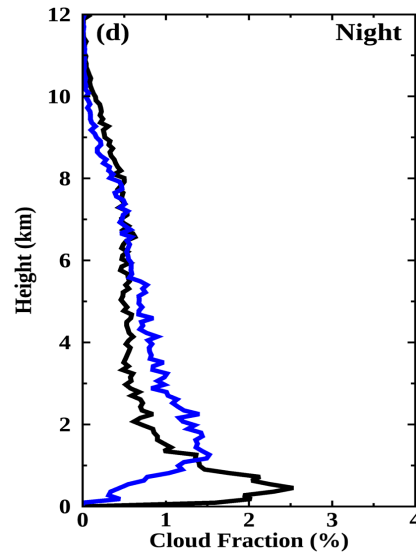
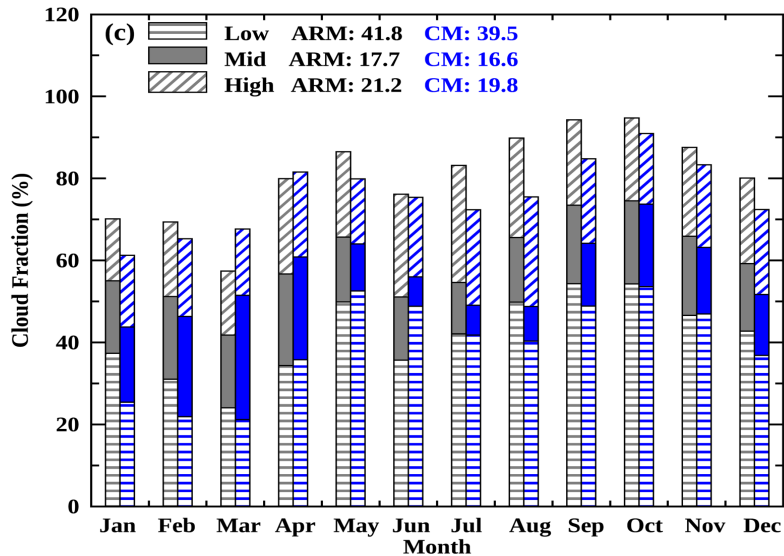
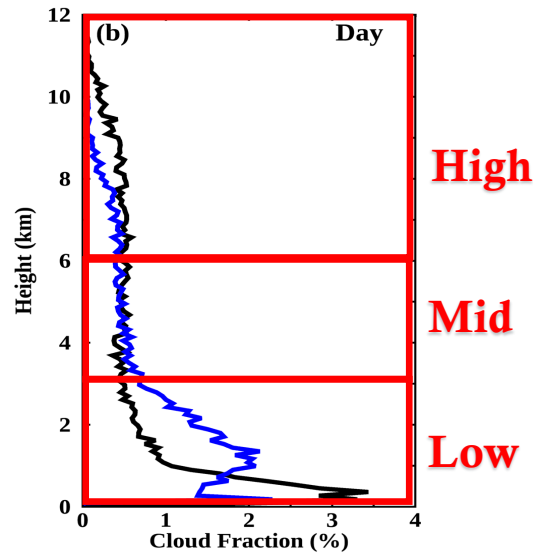
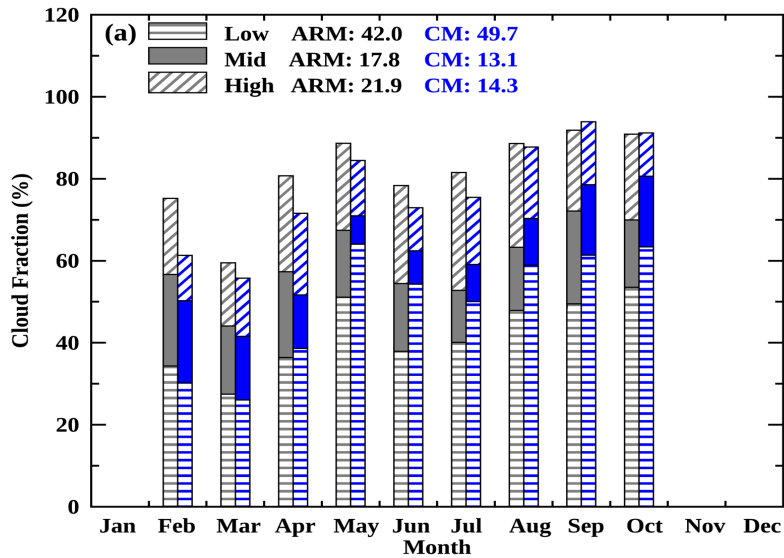
Sensitivity of CM T_{top} & Z_{top} retrievals to cloud locations

All samples are from 12-month averages



- For low clouds ($Z_{\text{top}} < 3$ km), CM retrieved T_{top} (Z_{top}) are colder (higher) than ARM
- Night time differences are larger
- For high clouds ($Z_{\text{top}} > 6$ km), CM retrieved T_{top} (Z_{top}) are warmer (lower) than ARM

Cloud occurrence frequency for different height levels



- Day time: CM detects more low-level clouds and less high-level clouds compared to ARM, especially in summer months
- Consistent with CM underestimate Z_{top} for high clouds in summer
- Nighttime: cloud fraction for different height levels are similar to ARM observations

Summary

1. CERES-MODIS (CM) Ed4 retrieved **cloud fraction agrees well** with ARM radar-lidar observation, annual mean differences are 5%.
2. CM Ed4 retrieved **cloud top temperatures are warmer** than ARM cloud top temperature in summer, and **cloud top heights are 0.2-1.5 km lower**. CM and ARM cloud temperature and height agree better in winter and autumn.
3. CM retrievals are closely related to locations of clouds. It retrieves **warmer cloud temperatures and lower cloud top heights for high clouds**, which contribute to the difference between CM and ARM in summer months.
4. CM retrieve slightly more low clouds and less high clouds compare to ARM.

Identification of convective initiation over ARM SGP using satellite cloud property retrievals.

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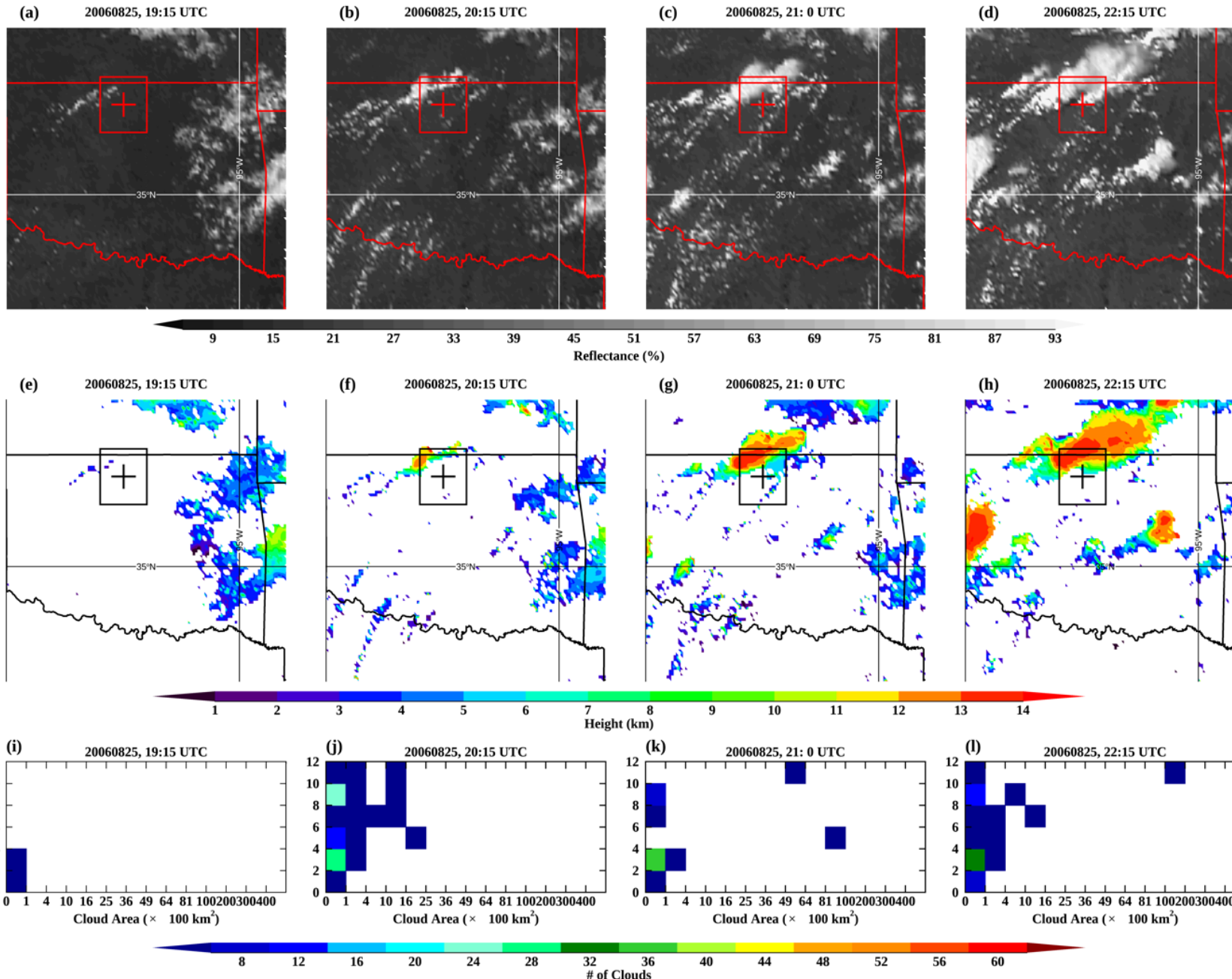


Data and Methodology

- GOES pixel level data with spatial resolution of 4km and temporal resolution of 30 mins
- Use CERES algorithm retrieved cloud optical depth and cloud top height (Z_{top}) from GOES observation over the ARM SGP site
- Create a cloud mask for all contiguous cloudy pixels, and count number of clouds with area and $> 10\%$ of their Z_{top} fall into different area and height bin range

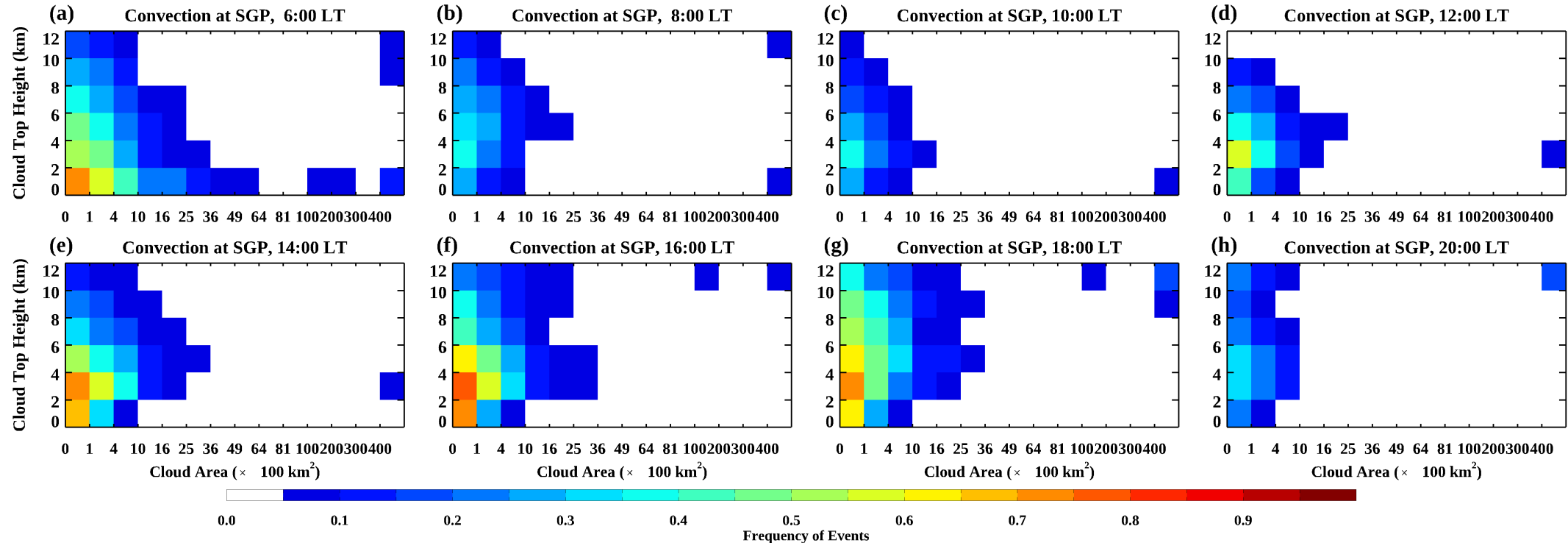
Cloud type	Definition
Shallow cumulus	Clouds with $Z_{\text{top}} < 6$ km and area < 400 km ²
Convective initiation	Clouds start as shallow cumulus and grow into deep convection (DC) in the same domain

A locally initiated deep convection case at ARM SGP on 2006/08/25



- At 19 UTC (1pm LST), only a few shallow cumulus clouds at SGP, area $< 100 \text{ km}^2$, $Z_{\text{top}} < 4 \text{ km}$
- From 20-22 UTC, clouds first develop in height and then grow in area.
- At 21, 22 UTC, some small clouds with area $< 100 \text{ km}^2$, $Z_{\text{top}} < 4 \text{ km}$ also developed near SGP
- We can use this method to classify cloud types, monitor the evolution of cloud systems in area, height and population, and evaluate model simulation of cloud systems

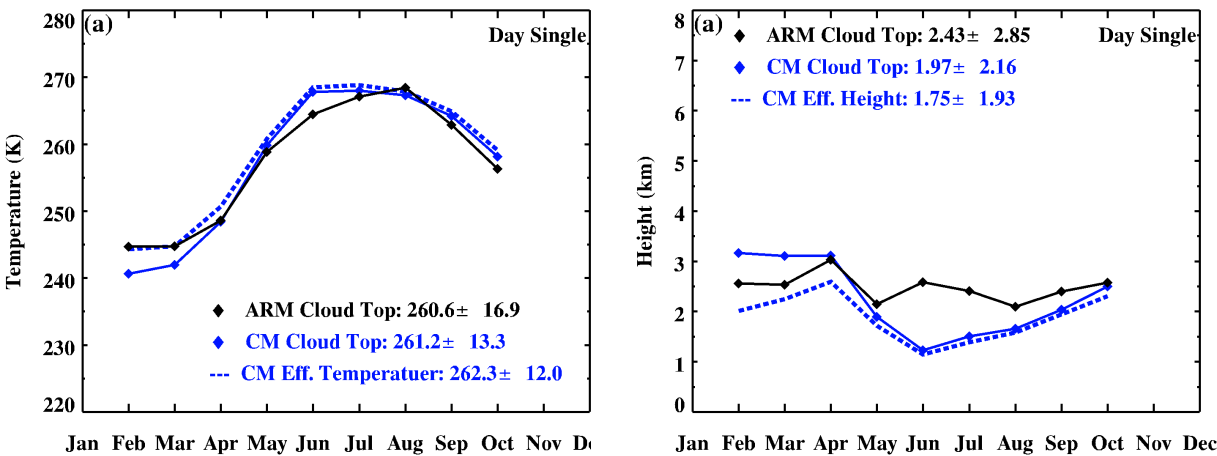
Statistics of afternoon convective initiation



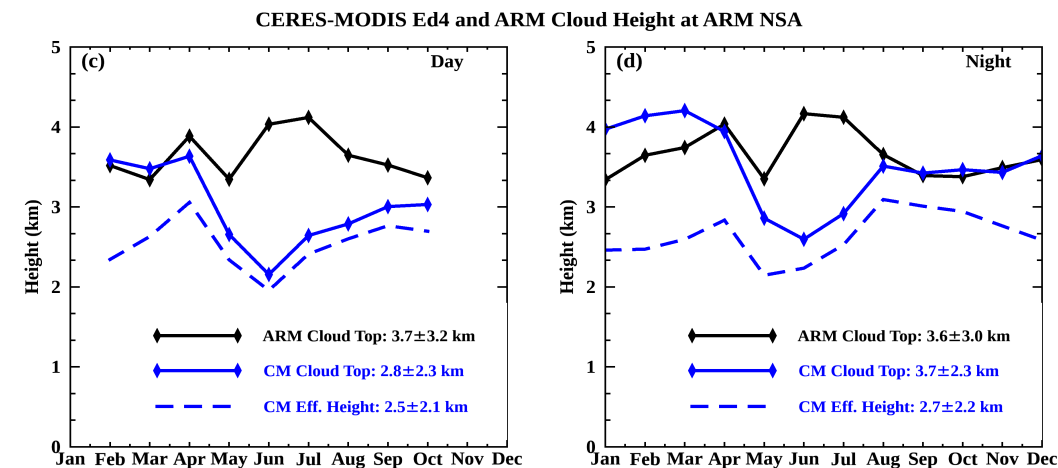
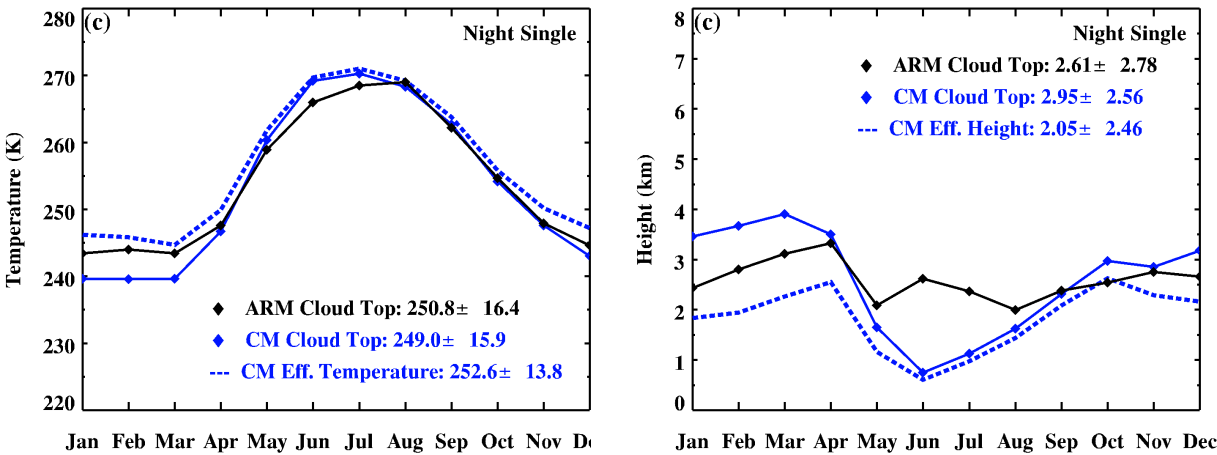
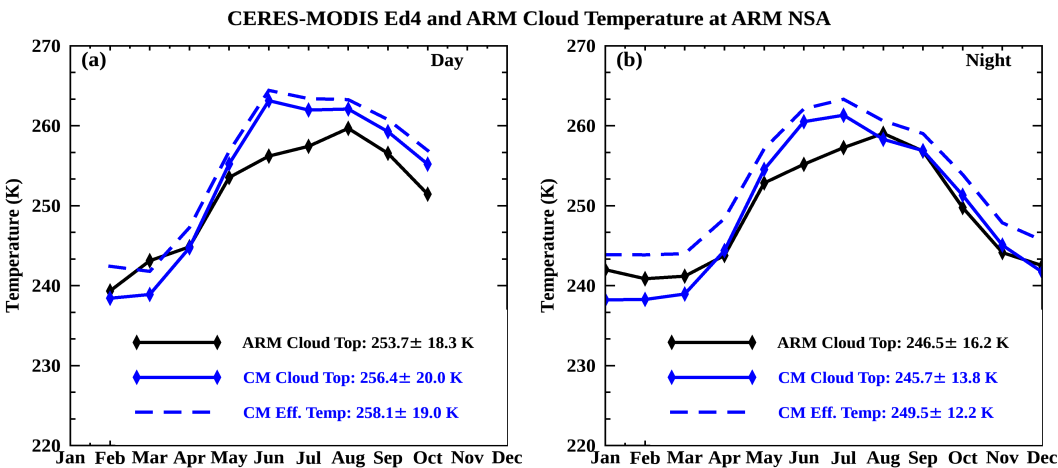
- To study surface influence on convective initiation, we further select convection initiation in the local afternoon (12-18 pm) in summer months
- Able to characterize the development from shallow cumulus to deep convection in the local afternoon, with the peak in cloud top and area at 18 LST
- Peak in cloud area and cloud top height at 6 am LST at SGP is the nocturnal deep convection developed over the Rocky Mountains in the previous afternoon

Supplemental Material

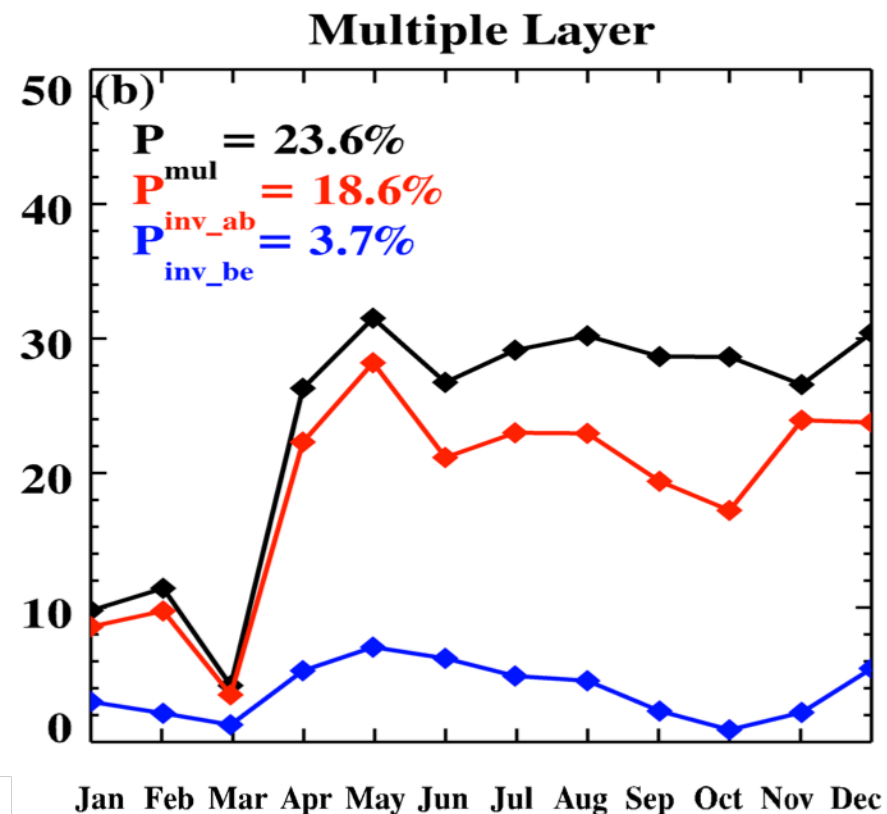
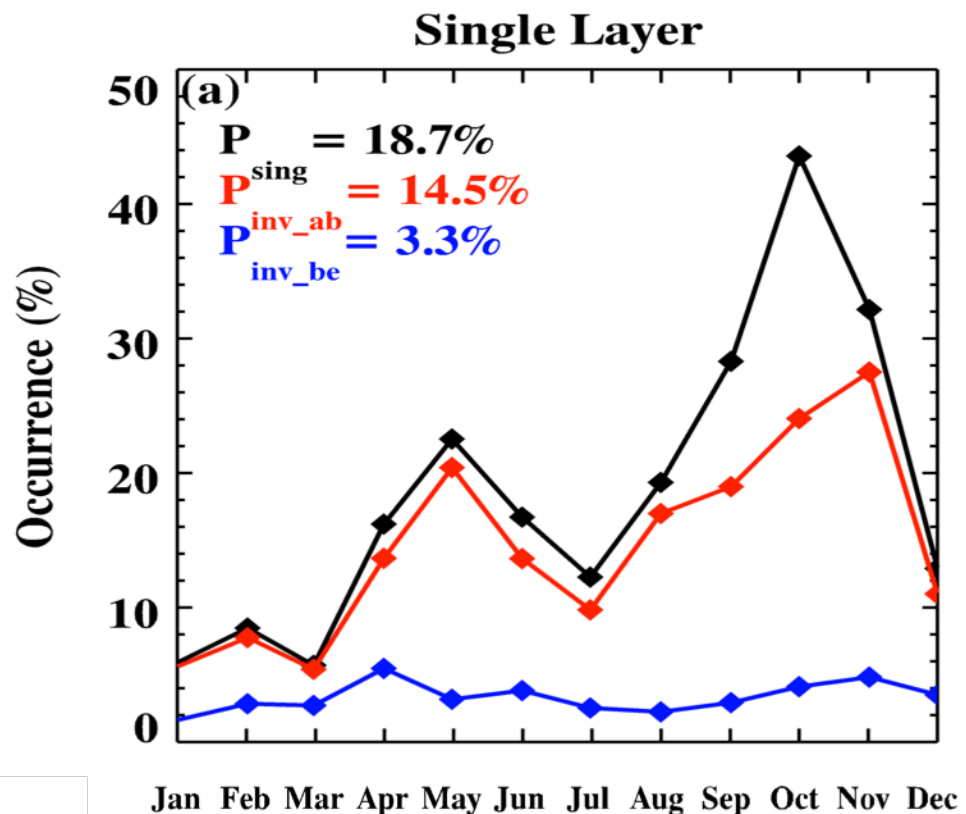
Monthly Mean Cloud Temperature and Height for single-layer cloud



Monthly Mean Cloud Temperature and Height for all Clouds



Occurrence frequency of single- and multilayer mixed-phase clouds from ARM observations



CERES-MODIS Cloud Properties Retrieval Algorithm

- **Cloud fraction:**

- Use MODIS cloud mask for each pixel, calculated cloud fraction for each footprint

- **Effective radius (r_e), optical depth (τ), liquid water path (LWP):**

- Use observed radiance at 0.67 μm and 3.7 μm , and an iteration process to retrieve r_e , τ , respectively

$$LWP = \frac{3}{2} r_e \tau$$

- **Effective Temperature (T_{eff}):**

- Using an iterative process to match the observed brightness temperature at 10.8 μm .

- **Effective Height (Z_{eff}):**

$$Z_{eff} = \frac{T_{eff}(CERES) - T_{sfc}(GMAO)}{\Gamma}$$

Overview of CERES Cloud Retrieval

